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Application of High Powered Lasers to Perforated Completions

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ABSTRACT

As part of the process of drilling an oil or gas well, a steel production casing is often inserted to the bottom of the well and sealed with cement against the productive formation. Openings must be made through the steel casing wall and cement and into the rock formation to allow formation fluid to enter the well. Conventionally, a perforator is lowered through the casing on a wire line. When it is in the correct position, bullets are fired or explosive charges are set off to create an open path between the formation and the production string. As effective as those processes are in creating a hole or tunnel, they alter the surrounding rock and cause formation damage around the created tunnel. The permeability of the altered zone is significantly less than virgin formation by as much as 80%. The petroleum industry welcomes new perforation technologies that not only create holes effectively but also minimize the formation damage. This paper will present the feasibility study results of application of high power lasers to perforation completions and focus on methods for creating deep holes in rocks by high power lasers.

INTRODUCTION

In the petroleum industry, perforating is a process of piercing the casing wall and the cement behind it to provide tunnels through which formation fluids may enter the wellbore. Current technology uses a perforating gun, or perforator to make these tunnels. The completion crew lowers the long cylindrical gun down the production casing or liner until it is opposite the reservoir zone. The bullets or special explosive charges carried by the perforator are aimed at the walls of the casing and shoot smooth, round holes in the casing and penetrate the rock as well (Figure 1)[1]. The high velocity shaped charge jet creates high shock pressure of 1.5 million psi at tunnel entrance to 150,000 psi at the perforation tip, which comminutes the adjacent rock, fractures sand grains, fails inter grain cementation, debonds clay particles, and creates tunnels which are typically 0.25 to 0.4 inches in diameter and 6 – 12 inches in length [2-4]. This mature technology has some disadvantages such as (1) lack control of hole size and shape, and (2) low flow performance due to reduction of permeability of perforated or crushed rock. Permeability reduction factor values (permeability ratio of crushed zone to rock matrix) of 0.1 to 0.7 were reported in previous studies [2-4]. Recent advances in high power laser technology provides a new tool to replace the current perforating gun for creating the holes. The laser perforator has the flexibility of drilling holes with different sizes and shapes. Previous laser rock tests also confirmed the increase of permeability of laser-drilled rocks. Laser-induced

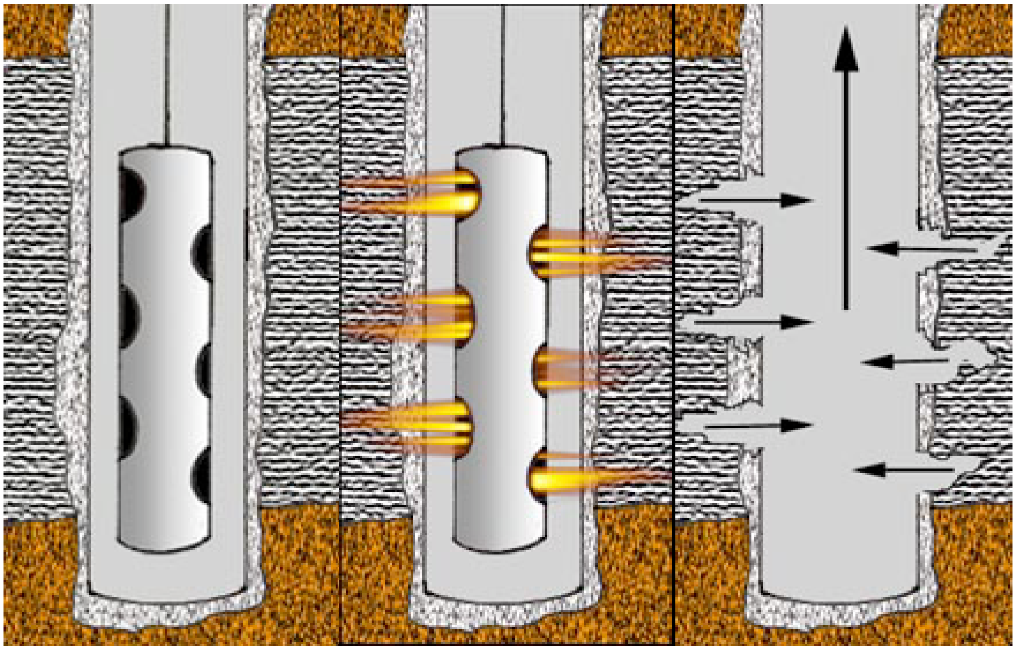

Figure 1. Conventional perforation gun is lowered to production zone. Special explosive charges carried by the perforator are aimed at the walls of the casing and shoot smooth, round holes in the casing and penetrate the rock as well.

permeability increase as high as 500 –1000% was reported on Berea grey sandstone rocks drilled by high power laser beams [5]. The permeability increase is attributed to the microcracks that were formed due to laser-induced clay dehydration and thermal cracking. This paper presents the results from the preliminary study on drilling one inch diameter holes that are 2 – 5 inch deep by a continuous wavelength CO_2 laser. Three drilling methods and their experimental results in this preliminary study are presented here. The goal of the experiments was to drill a hole on rock as deep as possible using a series of laser bursts.

EXPERIMENTAL SET UP

Method One: Fixed Beam

This method is shown in Figure 2. A fixed, defocused beam of one-inch in diameter was fired on a rock with two 65^0 purging tubes in symmetrical configuration. The laser head can be lowered down to compensate the beam spot size change at the bottom of the hole as the hole gets deeper, but the available moving distance is limited by the purging tubes first and then the laser head itself.

In the experiment, the 1" defocused beam was pointed at a shale sample, 3" thick and 3" in diameter. The CO_2 laser power was 4000 watts and nitrogen flow rate from the two 65^0 purging tubes were set at 200 cubic foot per hour (cfh) each.

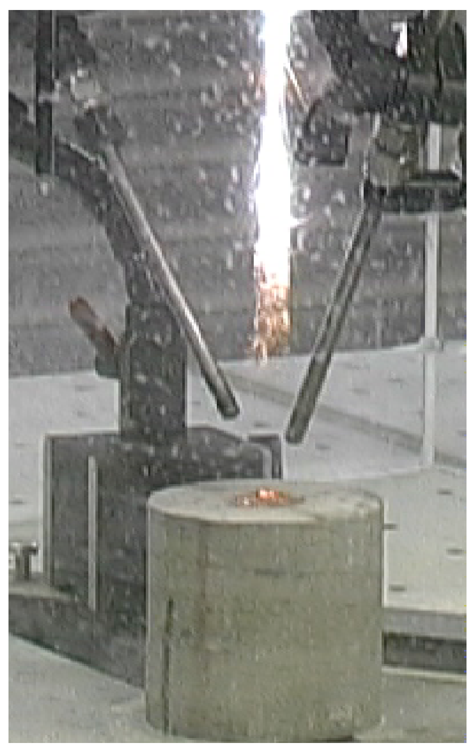

Figure 2. Method one set up

Method Two: Circular Motion Beam:

In this method, the rock sample was moved circularly by the workstation under the fixed vertical beam and purge gas.

This generated a relative circular motion of a defocused beam of 0.5 inch in diameter on the rock in a 0.5 inch diameter circle. A one inch diameter hole was formed by this circling beam after one revolution. A purging tube inside the hole circled together with the beam and was moved down after each revolution providing constant strong purging at the bottom of the hole as the hole got deeper. Figure 3 shows the circular motion beam in action of drilling a one inch hole on a shale sample (right) and relative positions of the beam, purging tube, and hole diameter created (left). A 4" diameter by 6" thick limestone sample was lased by a circularly moved CO_2 beam. The beam power was 4000 watts and the gas flow rate was 300 cfh. The laser head was moved down 0.5" between bursts. One burst here is defined as one revolution that the beam rotates. The beam moved at a linear speed of 50 inches per minute.

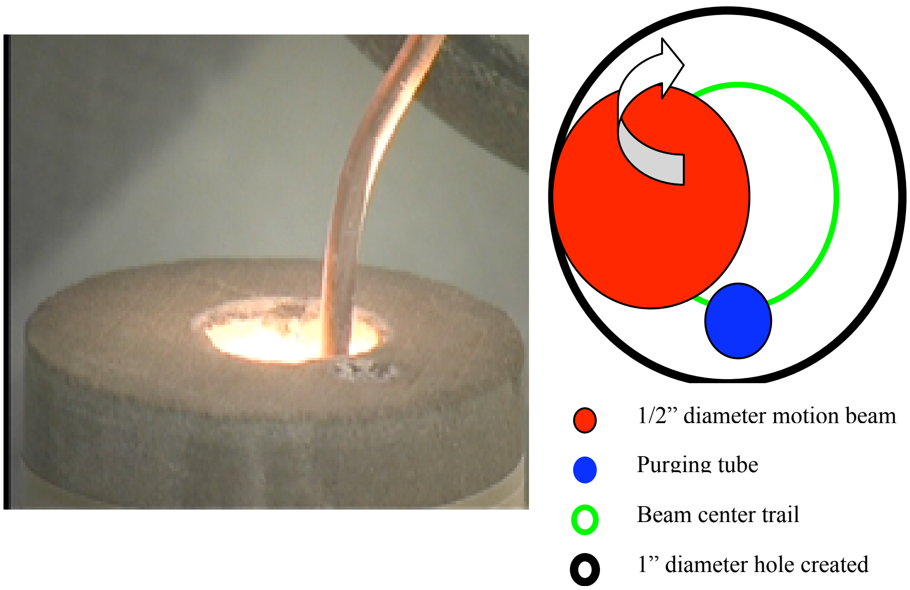

Figure 3. Circular motion beam in action of drilling a one inch hole on shale sample (right) and relative positions of the beam, purging tube, and hole diameter created (left).

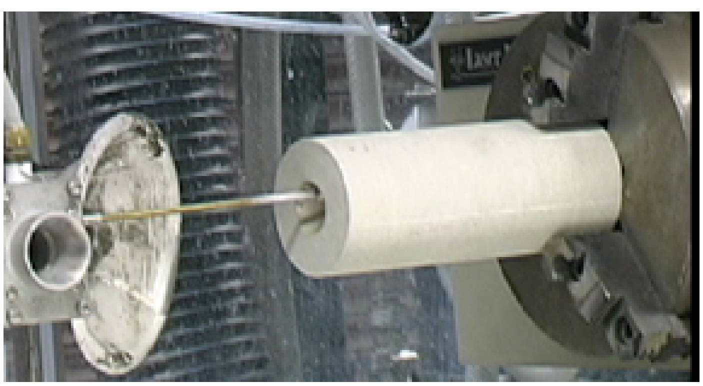

Figure 4. Rotary rock method was used at 2500 W laser power and 10,000 degree/min rotary speed to drill a deep hole into 7 inch thick sandstone core sample.

Method three: rotary rock method

A third method rotating the rock sample is shown in Fig. 4. Now the core rock sample is clamped by a rotary chuck and rotates around its own axis. The horizontal 0.5" diameter beam and 1/8"purging tube are positioned about 1/4 inch away from the core axis and kept stationary for each lasing cycle, then are adjusted between the circles to keep the constant spot size and gas flow at the bottom of the hole as the hole gets deeper.

A continuous wave CO_2 laser beam was used. The purging gas was nitrogen with flow rate 275 cfh. Two power levels, 4000 and 2500 watts and four rotary speeds, 10,000, 5,000, 3,000, and 2,000 degree/min, were tested.

TEST RESULTS AND DISCUSSIONS

Method one:

Figure 5. One inch by 1.8 inch deep hole drilled by four bursts of 4 second duration 4 kw CO_2laser beam on shale rock.

This hole drilled with Method one is shown in Figure 5. Four laser bursts with duration of 4 seconds each were applied to the center of the circular surface of the sample. The first three bursts drilled a hole 2.9" deep with no traces of melted rock. This gives a rate of penetration of 72.5 feet per hour for a 1 inch diameter hole. The fourth burst was not able to drill any deeper: it only melted the bottom surface of the hole, filling a small fraction of the hole depth with melted material. The final hole depth after the fourth burst was 2.85". Since each burst perforated holes about 0.6" deep, the focusing system was moved 0.5" down after the first burst and 1" after the third burst, in order to keep the constant beam irradiance near the hole bottom. Severe cracking of rock occurred at the 4th burst. Several lessons were learned from this experiment:

1. This simple setup works well for shallow holes less than 3 inches deep. The gas pressure used was high enough and efficient enough remove all traces of melted material for the given hole geometry (1 " diameter, same as beam spot size), up to a depth of 2.9".
2. The plume of debris exsolved went straight up, remained in the beam, and reduce the laser energy reached to the rock. In the worst case, rock debris reached to the focusing lens and caused lens damage.
3. The existing purging system was not able to remove the melted material during the 4th burst, probably due to the inability of the gas jet to reach such hole depths.

A better method would be to use a coaxial gas nozzle that would allow improved debri shielding of the optics and more efficient removal of the rock particles.

Figure 6. A one inch diameter, 5 inches deep hole drilled on limestone by CO_2 laser at 4 kW power.

Method two:

This method provides two major advantages over the fixed beam method: (1) the purging tube is placed inside the hole with vertical adjustment providing constant strong purging as the hole gets deeper, and (2) lased rock cools down before the beam makes a full circle and comes back to the same spot so overheating or melting of rock

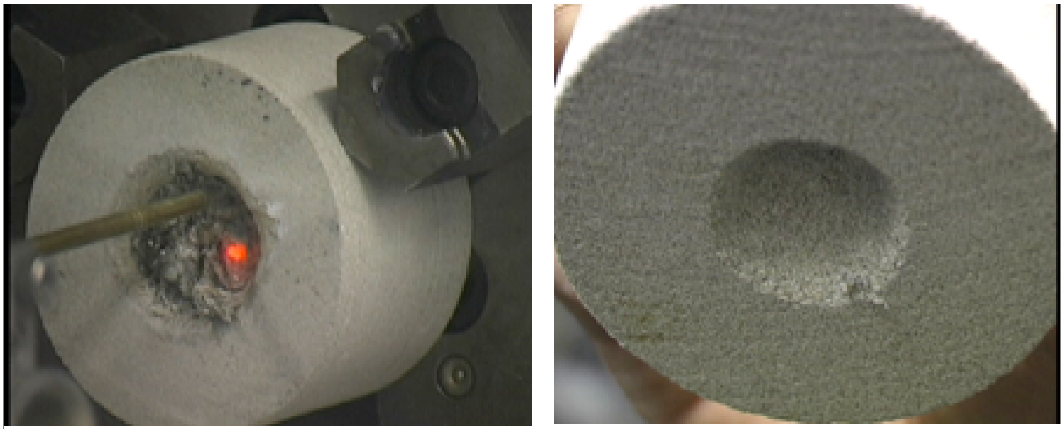

Fig. 7 Photographs showing a hole laser-drilled at 4000 W and 3000 degree/min rotary speed (left) and a clean hole drilled at 2500 W and 10,000 degree/min (right).

could be minimized.

The 1” diameter by 5” deep hole made on limestone is shown in Figure 6. As the hole became deeper, hole-tapering occurred rapidly because of energy absorbing secondary effects due to large hole aspect ratio of 5:1 and the diverging beam. In fact, the bottom diameter of the hole reduced to 0.20” from 1” at the hole opening. With this method, the relative positions of the beam and purging tube to the hole center are changing constantly in a revolution, so is the gas flow inside of the hole. As a result, the formed hole becomes asymmetrical.

Method three:

At high power (4000 W) and low speed (3,000 degree/min), the intense laser beam melted the rock and formed a glass phase that stayed in the hole (Fig. 7 left). Increasing rotary speed reduced the melting at fixed power. Optimal conditions were found at 2,500 W and 10,000 degree/min. A clean hole without any melted deposits (Fig. 7 right) was created at these optimal conditions.

The above optimal conditions were then applied to drill a deep hole in a 7 inch thick 3” in diameter sandstone core sample as shown in Figure 4. The 1/2” diameter beam with 1/4” offset from the core center created one inch diameter hole. The depth of the hole reached 3.3 inches after about 45 seconds beam exposure, but the hole diameter tapered from 1” at the open into 0.5” at 3.3 inch depth. This happened because the beam attenuation secondary effects increased as the hole became deeper. Better purging system design and/or replacing the defocus beam with a collimated beam will be studied to drill deeper holes with this method.

CONCLUSIONS

The preliminary perforating tests showed that all three methods tested could drill clean holes efficiently to different depths. The hole depth varied from 3 to 5 inches depending on the drilling method and was limited by the gas purging method, loss of beam intensity or too high an intensity causing melting and glass formation that prevents further drilling. The combination of a diverging beam and limited gas assist caused tapering of the drilled hole which limits the maximum depth that can be achieved. In addition, the relatively small rock sample sizes used led to fracturing and thermal effects. We recommend that large rock samples as big as a foot cube be used for perforation testing in the future to avoid such effects. The data obtained point to the need for improved beam delivery in terms of a collimated beam and gas assist that will protect the optics and remove the rock fragments efficiently.

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